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THESIS

COMPARISON OF JANUS(A) SIMULATED TERRAIN VEGETATION CODES TO MODIFIED TERRAIN VEGETATION CODES FOR THE JAVELIN ANTITANK OPERATIONAL TEST

by

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September, 1993

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Comparison of Janus(A) Simulated Terrain Vegetation Codes to
Modified Janus(A) Terrain Vegetation Codes for the Javelin Antitank Operational Test

by

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ABSTRACT

The purpose of this thesis is to compare and analyze the effects of the Janus(A) default terrain database and a Janus(A) modified terrain database on a modeled Javelin operational test. An eight meter resolution terrain database was used to create the modified Janus(A) terrain. The eight meter resolution terrain database was extracted from the Perspective View Generator and Analysis Systems for Unmanned Sensors Terrain Database Creation System. Analysis using nonparametric statistics and graphical methods showed that the vegetation code distributions for the default terrain and the modified terrain were not the same. Three scenarios were run using each terrain file, and when the results were compared, the detection ranges were found to be different in the areas where intense vegetation modifications had to be made.

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EXECUTIVE SUMMARY

A. PURPOSE

The purpose of this thesis is to compare and analyze the effects of the Janus(A) default terrain database and a Janus(A) modified terrain database on a modeled Javelin operational test. It is part of the Model-Test-Model (M-T-M) research program sponsored by the U.S. Army Training and Doctrine Command (TRADOC), Analysis Command-Monterey (TRAC-MTRY) and the Test and Experimentation Command (TEXCOM), Experimentation Center (TEC). This is part of an ongoing effort to accredit the M-T-M concept.

The research for this thesis was accomplished in three phases. First, the operational test area was defined and two duplicate Janus(A) terrain database files were created. The terrain characteristics of one of the files were modified so that the vegetation information per 50 meter grid cell more accurately represented that of the actual test site. Next, a data analysis comparison was done on the two files to determine if their distributions are the same. Lastly, the Javelin test scenarios were run using both terrain files and the results compared using statistical procedures.

B. BACKGROUND

With projected budget cuts, fewer defense dollars will be available for operational test and evaluation (OT&E) of weapon systems. The M-T-M concept integrates operational field tests with simulation models to increase the effectiveness and efficiency of operational tests. The concept of M-T-M is to use high resolution simulation model(s) before the operational test to help design efficient and meaningful test scenarios and tactics, and after the field test to expand the evaluation effort to include testing other scenarios and tactics. One of the models currently in use is Janus(A), a computer-based, two-sided, high resolution, stochastic combat simulation model designed for Army training and combat development. It uses a digitized terrain database to represent a portion

of the real terrain. This database is based on Digital Terrain Elevation Data (DTED) Level I data provided by the Defense Mapping Agency.

C. RESULTS

The results of the analysis indicated that vegetation code distributions of the default terrain database and the modified terrain database were not the same. Three scenarios, a deliberate night defense, a deliberate day defense and a hasty day defense were modeled using each of the terrain databases. Data was collected using the detection range of an enemy vehicle by the opposing force as the measure of effectiveness. The three different scenarios were each run eight times on each terrain database. Analysis indicated that there was a statistically significant difference between the detection ranges for two of the scenarios. These two scenarios were run on terrain that required extensive modification to the vegetation codes. No significant difference was noted in the third scenario. Very few modifications of the terrain data were needed in the area where this battle was fought.

D. RECOMMENDATIONS

The results do not suggest that the Janus(A) model is invalid. However, the results do indicate that further improvements to the terrain database will further reduce the errors between results based on the simulated terrain and the actual terrain. This will result in better simulation of the line of sight, and the effectiveness of a weapon system for a given scenario and tactic. Thus, the overall results of the model should better reflect the operational test results.

I. INTRODUCTION

A. RESEARCH OBJECTIVES

This thesis is part of the Model-Test-Model (M-T-M) research program sponsored by the U.S. Army Training and Doctrine Command (TRADOC), Analysis Command-Monterey (TRAC-MTRY) and the Test and Experimentation Command (TEXCOM), Experimentation Center (TEC). The M-T-M concept integrates operational field tests results with simulation models. As part of an ongoing effort to accredit the M-T-M concept, this thesis will compare Janus(A) model terrain to the actual test site terrain for the Javelin antitank weapon system.

B. BACKGROUND

With projected budget cuts, fewer defense dollars will be available for operational test and evaluation (OT&E) of weapon systems. The M-T-M concept integrates operational field tests with simulation models to increase the effectiveness and efficiency of operational tests. The concept of M-T-M is to use high resolution simulation model(s) before the operational test to help design efficient and meaningful test scenarios and tactics, and after the field test to expand the evaluation effort to include testing other scenarios and tactics. Thus, the operational test and evaluation (OT&E) community will work with analysts using simulations and models to design operational tests and then use these models to make predictions on the employment, manning level, supply rate, etc. of the weapon system. One of the models currently in use is Janus(A), a computer-based, two-sided, high resolution combat simulation model designed for Army training uses and combat development. In October 1990, Mr. Walter W. Hollis, Deputy Under Secretary of the Army (Operations Research) tasked TEC at Fort Hunter Liggett, California to improve the M-T-M methodology [HOLL 89]. TEC enlisted TRAC-MTRY to conduct research in support of the M-T-M

concept. TRAC-MTRY's research efforts are directed toward the validation and accreditation of the M-T-M concept using the Janus(A) high resolution combat simulation model.

The model terrain in Janus(A) is a digital representation of the actual test site terrain located at Fort Hunter Liggett. Extensive efforts have been made to simulate the test site terrain as closely as possible because terrain characteristics affect the movement rates and, most importantly, the line of sight (LOS) of combat systems. If the combat simulation model terrain accurately represents the test site terrain, one can expect a more realistic simulation of the LOS and the effectiveness of a weapon system for a given scenario and tactic. Also, the weapon system's tactical emplacement can more closely reflect actual field locations which affect both range and LOS. Thus, the overall results of the model should better reflect the operational test results if the errors between the model terrain and the actual terrain are reduced.

C. RESEARCH METHODOLOGY

The research for this thesis was accomplished in three phases. First, the operational test area was defined and two duplicate Janus(A) terrain database files were created. The vegetation codes in one of the files were modified to more accurately represent the actual test site terrain. To help ensure accuracy, two separate terrain walks were conducted to study the vegetation and determine densities for various tree stands from different locations in the test site area. Information was also gained from an eight meter resolution terrain database extracted from the Perspective View Generator and Analysis Systems for Unmanned Sensors (PEGASUS) replicator. The PEGASUS terrain database creation system will be explained in a later chapter. Next, a data analysis comparison was done on the vegetation code distributions from an identical one kilometer area in each of the two files to determine their similarities and differences. Third, the Javelin test scenarios were run using both terrain files and

the results compared using statistical procedures. The measure of effectiveness (MOE) used to compare the results was the detection range of an enemy vehicle by the opposing force.

D. ORGANIZATION

This thesis is organized in five chapters. Chapter II describes the Javelin and the Model-Test-Model concept. Chapter III contains a description of Janus(A), the PEGASUS replicator, the process required to build a terrain database and the methods used to perform terrain modifications. Chapter IV contains the discussion and results of the vegetation code analysis and the Javelin scenario runs. A summary of the findings and recommendations is given in the last chapter.

II. JAVELIN AND THE MODEL-TEST-MODEL CONCEPT

A. JAVELIN

The success of the U.S. in the Persian Gulf War has prompted potential hostile countries to upgrade their military forces with more advanced weapon systems. Thus, the U.S. military can expect to face enemy armored vehicles with considerable improvements in lethality, mobility and survivability. To meet this new threat, the U.S. has had to continue to improve and field new anti-armor weapon systems, capable of defeating these new threats. Currently, the U.S. forces rely on three antitank weapon systems: the tubular launched optically sighted wire guided missile (TOW), the Dragon and the antitank 4 missile (AT4). The TOW is a wire guided antitank weapon capable of destroying enemy armored vehicles at up to 3750 meters. The AT4 is a hand held, fire and forget weapon, capable of killing thin skinned armored vehicles at ranges from 65 to 300 meters. The AT4 replaced the light anti-armor weapon (LAW) to give the infantryman more firepower to defeat the new enemy armored personnel carriers. The Dragon is a medium antitank wire guided missile capable of destroying enemy armor out to 1000 meters.

However, with the new advances in enemy armor, the U.S. has developed a new more effective medium antitank missile, the Javelin, to replace the Dragon.

> The Javelin is a top attack, man portable antitank missile which gives the infantryman an increased capability to engage and defeat threat tanks and other armored vehicles. It is a fire and forget weapon system which significantly increases gunner survivability because it no longer requires a gunner to track the target for the duration of the missile's flight. [JAVE 92]

The Javelin's greater lethality comes from its ability to attack its targets from the top where the armor is the thinnest, its 2000 meter plus

range and its improved warhead. The Javelin consists of three components, the command launch unit (CLU), the launcher and the missile, Figure 1.

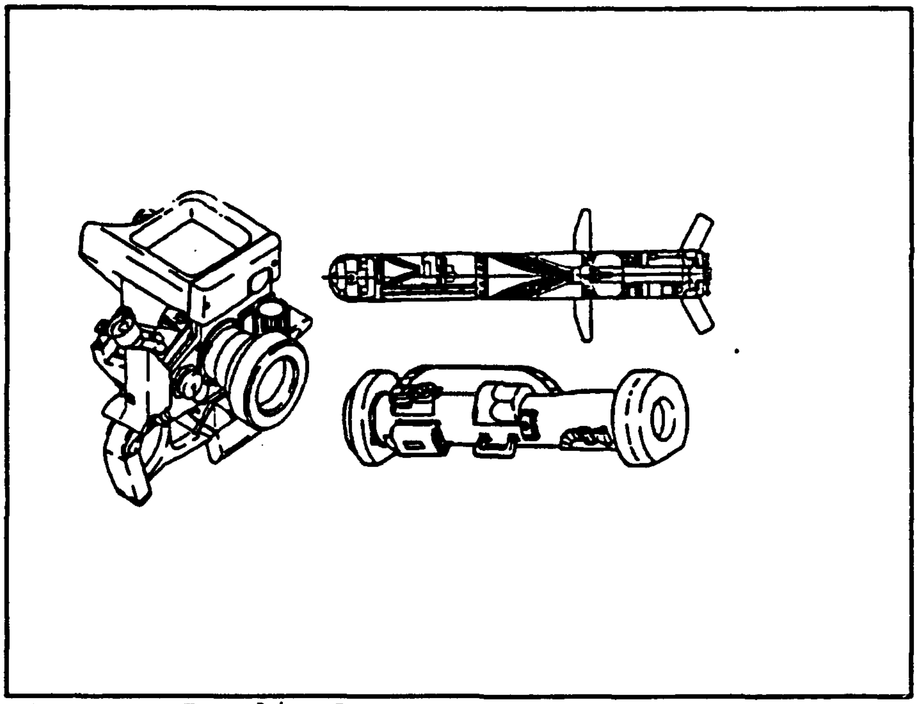

Figure 1 Javelin Components

The heart of the Javelin is the CLU. It is an integrated day/night sight unit that uses conventional optics or thermal imagery to paint a picture of the target to the misile's memory allowing it to track the target on the battlefield. The Javelin has a rate of fire of three rounds per minute. These improvements compared to the DRAGON's, 1000 meter range, rate of fire (two rounds per minute), wire guided missile and inability to attack the most vulnerable parts of enemy armored vehicles give the dismounted company team greater lethality and increased survivability. Introduction of the Javelin to the battlefield will better equip U.S. forces to meet and defeat new threat armor technology.

B. MODEL-TEST-MODEL CONCEPT

The overall goal of the Model-Test-Model concept (M-T-M) is to improve operational test effectiveness. M-T-M accomplishes this by using

simulation models from which the operations analyst attempts to predict operational test data for a particular test scenario. The simulation model provides insights into the feasibility of test scenarios and test objectives. This information is used by operational testers at the Operational Test and Evaluation Command (OPTEC) to make a more efficient test design and by the program manager to help him make more accurate decisions affecting the acquisition process. Application of M-T-M includes a force on force, free play field test that requires cooperation and coordination between testing and analysis/modeling communities. This means that the modelers and analysts must be intricately involved with the planning and designing of tests and the data collection and data reduction techniques. This coordination will ensure that all parties involved understand and account for all the peculiarities and problems associated with the operational test.

There are five phases to M-T-M: long term planning, pretest modeling, field test, post-test modeling and accreditation. Upon accreditation of the model, it can be used by military agencies to conduct careful extrapolation to other scenarios.

1. Phase 0 (Long Term Planning)

Phase 0 begins with the analyst and tester defining responsibilities. During this phase, a Memorandum of Agreement (MOA) and a Project Coordination Sheet are signed by the organizations involved to identify working relationships, specific roles and what type of product is expected.

2. Phase I (Pretest Modeling)

This is a modeling phase that relies on high resolution combat simulation models to aid in planning the operational field test. The goal is to save time, money and resources in the test design. In this phase, the model is prepared and executed with the proposed scenarios. The scenarios should incorporate the restrictions developed by the test personnel (e.g., size/characteristics of the terrain box, weapon

capabilities, rates of advance, force size, etc.). The scenario restrictions and the tactics for each scenario are given to the weapon system proponent to provide the proponent subject matter experts (SME) a doctrinal review of the tactics and test design. After the model is run, the test design and tactics are refined as necessary. The results from the model are used by the test designers to focus data collection efforts, identify external and internal constraints that will have a negative impact on the test, and minimize the possibility that test objectives will not be accomplished. Phase I continues until the model predicts that the test objectives will be met.

3. Phase II (Field Test)

During this phase, the operational effectiveness and weapon system capabilities are evaluated. The first part of this phase is the Initial Operational Test and Evaluation (IOTE). In the IOTE, maneuver units perform the successful battle tactics developed by their unit leaders in the pretest modeling phase. The tactics are revised as appropriate, based on the outcomes of the IOTE. The Operational Test (OT) tactics must be unscripted to increase the validity of the OT, but the tactics must remain within the test restrictions. It is crucial that the modeler understand how the test was conducted and works with the data reduction personnel to understand how the data was collected and screened. At the conclusion of the field test phase, the modeler obtains the necessary data and begins the post-test modeling phase.

4. Phase III (Post-Test Modeling)

In this phase, the model is used to provide analysis and feedback to test personnel, to explain unexpected test results and to guide the modifications of further trials, if necessary. Successive iterations of the model are run to calibrate the model's algorithms and model data. The modeler must be careful not to calibrate the model to a specific trial, as the goal is to have the model represent the field test within specified

statistical tolerances. These tolerances are usually defined by the agency responsible for accrediting the simulation model.

5. Phase IV (Validation/Accreditation)

In phase four, the "calibrated" model is used to extrapolate the test results to conditions, scenarios and threats that were not tested due to cost, time, or equipment/environmental constraints. This occurs after the model is validated and accredited. Validation of a model is the process of determining that a model is an accurate representation of the intended real-world entity from the perspective of the intended use of the model [ARMY 92]. Accreditation is performed by OPTEC, based on experience and expert judgement that the model is adequate for its intended use [ARMY 92]. It is the certification that the model is acceptable for use for a specific type of application [ARMY 92]. The credibility of the extended results naturally depends on how far an extension is from a calibration point (e.g., scenario in jungle terrain extended to desert terrain or Mission Oriented Personnel Posture (MOPP) 0 to MOPP 4). Thus, the modeler/analyst must take care not to extend the model results to a point where the tactical character of the battle changes so much that the calibration representation is no longer valid.

This thesis will support TRAC-MTRY's ongoing accreditation effort for M-T-M using the Janus(A) high resolution combat simulation model. The focus will be to compare and analyze the effects of the Janus(A) terrain and the actual terrain characteristics on the modeled operational test. The detection range of an enemy vehicle by the opposing force will serve as the MOE.

III. TERRAIN SIMULATION PROCESS

A. JANUS(A) COMBAT MODEL

1. Overview

Janus, named for the two-faced Roman god who guards portals, is an interactive, computer-based, war-gaming simulation for combat operations at the brigade and lower level [JANU 93]. The Janus combat simulation model has evolved through several versions, beginning with the Janus(L) version that was developed by the Lawrence Livermore National Laboratory (LLNL). The U.S. Army TRADOC Analysis Command, White Sands Missile Range, New Mexico (TRAC-WSMR) acquired this prototype and developed Janus(T) to meet combat development needs. From the Janus(T) version came the Janus Army or Janus(A) version which is used for combat development and training needs. Janus(A), version 3.0, is the most current version now in use by the Army. Today, Janus(A) is developed, maintained and distributed by TRAC-WSMR, and is fielded throughout the Army as a tool for trainers and analysts in testing, research and combat development.

Janus(A) is a "high resolution, event-driven, two-sided, closed, stochastic, ground combat simulation" [JANU 93].

- 'High resolution' means that the smallest object modeled in the simulation is an individual weapon system (e.g., a soldier and his M16 rifle).
- 'Event driven' means the state of the simulation is updated asynchronously when a combat event occurs.
- 'Two-sided' refers to the two opposing forces, Blue and Red. The Blue force and Red force are simultaneously directed on separate monitors by two different sets of players. Janus(A) can be used in a single player mode as well.
- 'Closed' means the disposition of the opposing force is unknown, except those locations found by direct intelligence reports from friendly forces.
- 'Stochastic' means that certain events are not predetermined, but occur according to the laws of probability.

- 'Ground combat' means the principal focus of the simulation is on ground maneuver and artillery combat units.

Janus(A) is also capable of simulating the effects of weather, rotary and fixed wing aircraft, day and night visibility, chemical environment, minefield employment and other variables. Janus(A) is written entirely in the VAX-11 FORTRAN language and currently runs on any Digital Equipment Corporation (DEC) VAX family computer using the standard VMS operating system.

2. Janus(A) Battlefield Terrain

The Janus(A) terrain database is a digitized representation of a portion of real world terrain, based on Digital Terrain Elevation Data (DTED) Level I data. The DTED Level I data is supplied by the Defense Mapping Agency (DMA). The data is converted from a profile plot to a contour plot for use in the Janus(A) computer simulation, Figure 2.

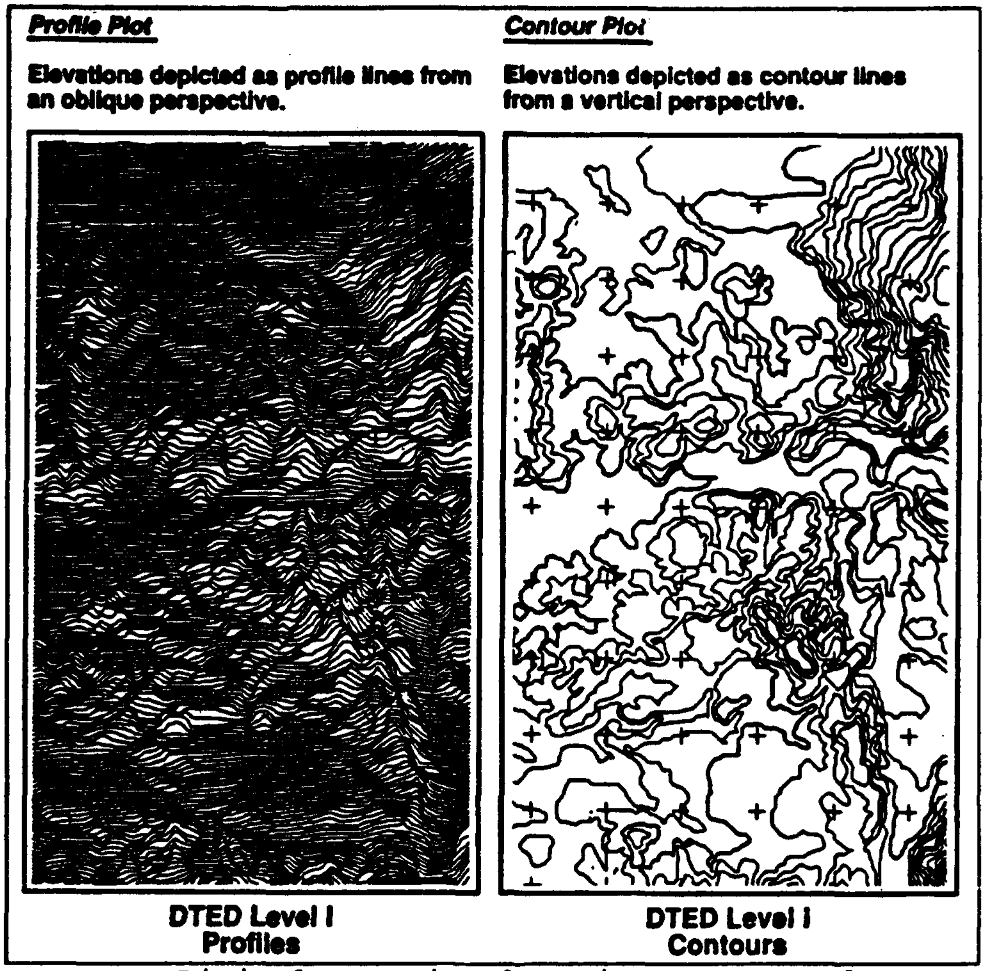

Figure 2 Digital Terrain Elevation Data Level I

Janus(A) provides the user a computer generated map image of the exercise area, showing terrain contours, forested areas, roads, rivers and urban areas. Within Janus(A), the user can initialize the size of the exercise area based on his needs. The exercise area is a square that is subdivided into 360,000 (600 x 600) grid cells. The user can vary the size (resolution) of the grid cells from 25m x 25m, 50m x 50m, 100m x 100m to 200m x 200m. Each grid cell carries the characteristics of the terrain: elevation, vegetation or urban area, density and height, road data, rivers and bridges within that grid cell. Each characteristic is assigned a numeric value that defines the characteristic within that grid cell. For example, a numeric value of five for vegetation defines the density and

height of the vegetation in that grid cell as a representation of the actual tree height and density for that geographic area. All of these characteristics are assumed constant throughout the grid cell. By reducing the size of the grid cells, the user is able to better represent changes in the elevation, vegetation, urban areas, road networks and rivers which should better simulate the real world terrain being modeled. This thesis will explore this question in Chapter IV by running the Javelin scenarios on the generic Janus(A) terrain and on the modified 50 meter resolution "real world" terrain (described below).

B. PEGASUS

1. Overview

The Perspective View Generator and Analysis Systems for Unmanned Sensors (PEGASUS) is a prototype terrain database creation system. It is being used by the Army Test and Experimentation Command (TEXCOM), Experimentation Center (TEC) at Fort Hunter Liggett, California to produce object material descriptors for the PEGASUS real-time perspective view generation replicator [BAER 91]. The object material descriptors are the information such as height, width, tree canopy shape and other attributes that describe various objects such as trees, buildings and vehicles. "The replicator is to provide substitute video images that are realistic representations of the battle maneuvers actually occurring in real time" [BAER 91]. The replicator can be perceived as a data flow through a sensor response system.

> The system flow starts with photographic measurements of targets, cultural features and terrain background. To these are added geographic and object size measurements to orient and scale the photographic data. The photographic input data is digitized, radiometrically calibrated, registered with location and scale information and stored on optical disk in a registered image database [BAER 91].

2. Terrain Database Creation

The PEGASUS database creation system is a transputer-based computer system, with numerous algorithms designed to input, measure and parameterize visual images into an object-oriented database. The transputers provide the parallel processing necessary to create the visual imagery of this complex database in close to "real-time". The terrain database creation software is depicted in Figure 3.

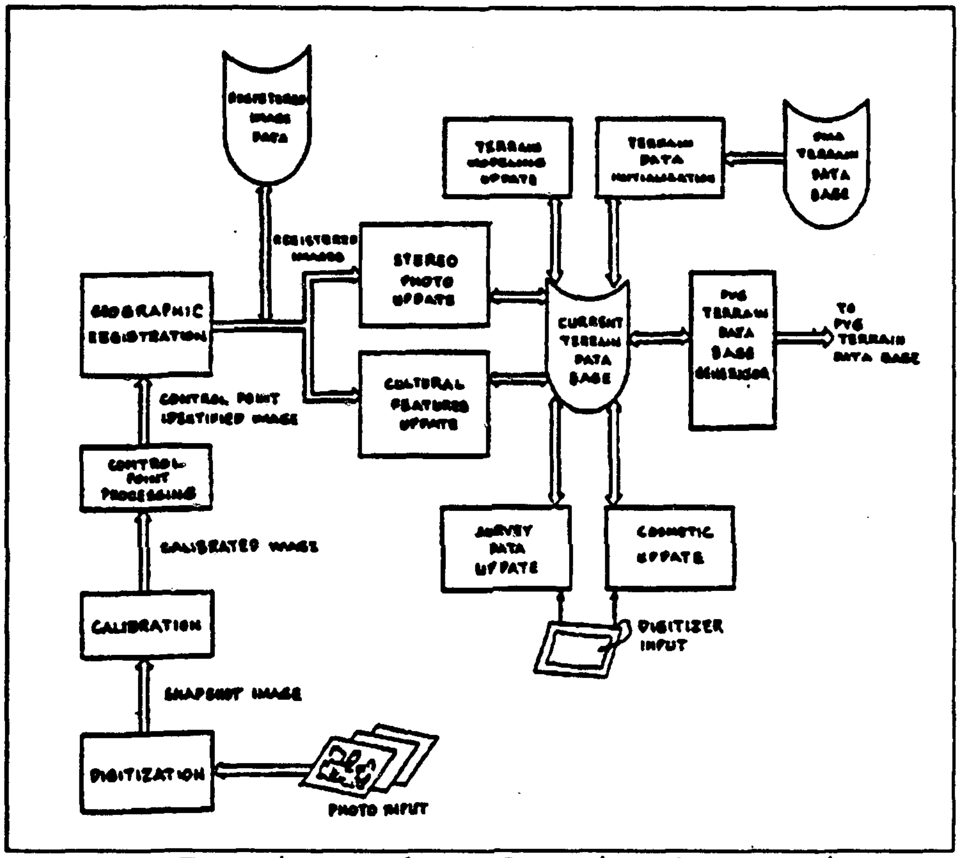

Figure 3 Terrain Database Creation System Diagram

The diagram shows the variety and flow of information used to create and update a PVG database. The system can use the elevation and vegetation code data supplied by DMA and the Waterways Experimentation Station (WES) respectively, or generate its own initial estimates. The result is an one meter resolution terrain database for a 375 square kilometer test area. This one meter terrain database can be expanded to a four meter, sixteen

meter and sixty four meter database by filtering and averaging high resolution information.

C. SCENARIO TERRAIN FILE

The scenario terrain file is the computer simulated terrain that represents the actual test site terrain. Within Janus(A) exist the Master Terrain Files (MTF) which are based on DMA DTED files. The analyst or trainer can customize his specific scenario terrain file using the Janus(A) terrain editor which is part of the Janus(A) Database Manager. This customizing process determines the modeled test site terrain, and thus determines the *Lines of Sight (LOS) and movement factors*. Each scenario terrain file consists of a terrain file (TERAIN###.DAT;#) and a terrain screen file (TSCRN###.DAT;#). This section will explain the processes used to make the Janus(A) and PEGASUS simulated terrain and discuss the role and products of agencies involved in the creation of model terrain.

1. Terrain File (TERAIN##.DAT;#)

The terrain file contains the digitized data derived from data supplied by DMA.

a. *DMA Process*

As discussed earlier, The data supplied by DMA is called the Level I Digital Terrain Elevation Data (DTED) which is used for all military activities and systems that require landform, slope and elevation in a digital format. The DTED Level I data is derived from imagery with a one degree by one degree cell size defined by the integer one degree latitudes and one degree longitudes of the geographic reference system *[DIGI 90]*. The vertical and horizontal datums are Mean Sea Level (MSL) and World Geodetic System (WGS) 84, respectively. The elevation data is expressed in meters and the information content is equivalent to a 1:250,000 scale resolution. DMA provides this data in a matrix structure with an ASCII labeled variable length record format.

b. *PEGASUS Process*

PEGASUS can use the DTED Level I data supplied by DMA as a baseline for the terrain file or generate its own. Using the DTED Level I data as a baseline creates no additional error problems because of the terrain refinement process in PEGASUS. Within PEGASUS, the Perspective View Database (PVDB) details the test scenario terrain area in resolutions of one, four, sixteen and sixty four meters and covers a 32.768 x 28.672 kilometer rectangular area. The coordinates of the rectangle conform to the Universal Transverse Mercator (UTM) conventions. The PVDB is organized into a Tile/Block/Post (TBP) structure. The PVDB is broken up into an 8 x 7 collection of tiles, Figure 4, and each tile is partitioned into a 16 x 16 array of blocks and each block contains an arrangement of data posts, Figure 5 [AKIN 89]. The posts contains the elevations, cultural feature indicators, gray shade values, surface normal indicators and sun shade flags required for the creation of the detailed terrain information.

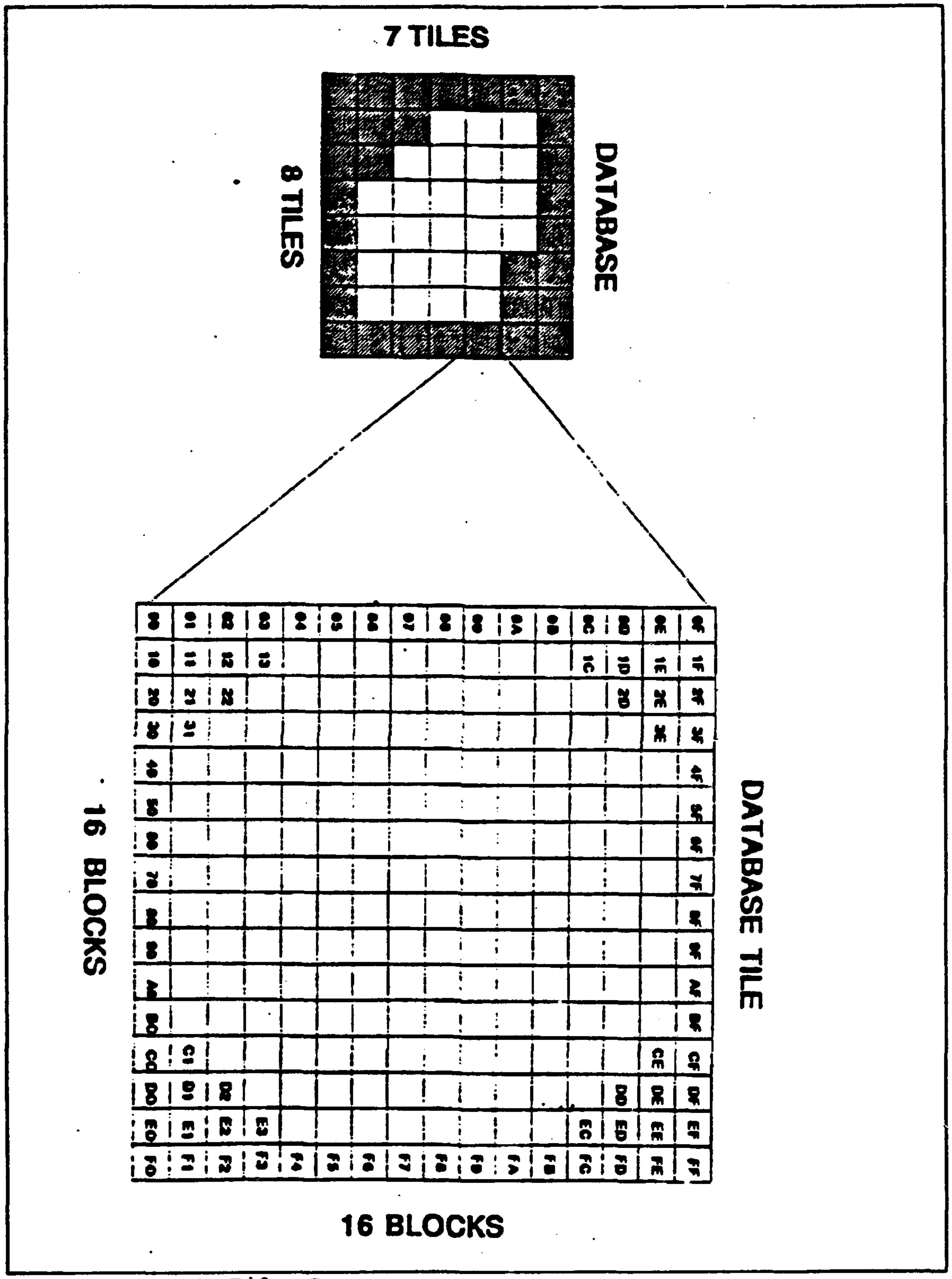

Figure 4 PVDB Tile Structure

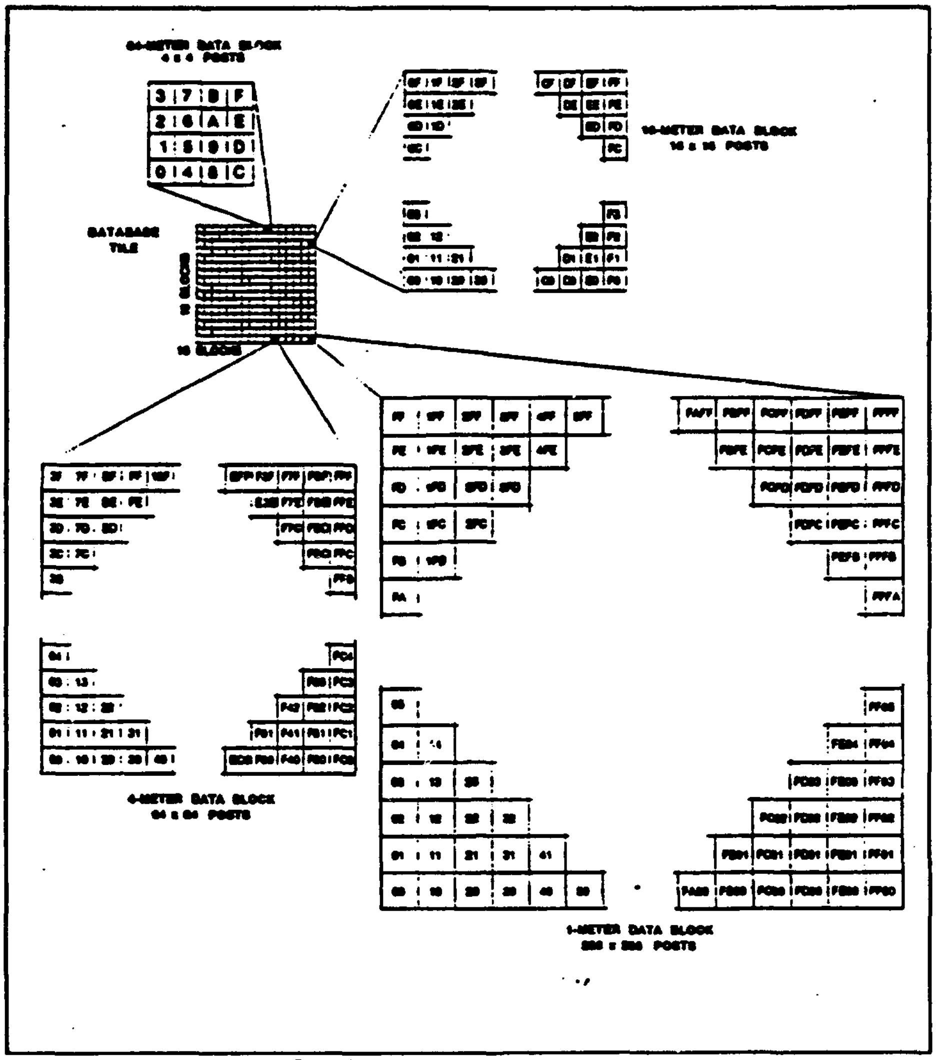

Figure 5 PVDB Block Structure

A tile represents an area of ground measuring 4096 x 4096 meters and a block represents an area measuring 256 x 256 meters. The following table shows the number of data posts in a block, which is dependent on the data resolution:

Table I POSTS WITHIN A BLOCK

Resolution	# of Posts
64 meter	4 x 4
16 meter	16 x 16
4 meter	64 x 64
1 meter	256 x 256

2. Screen File (TSCRN###.DAT;#)

This file contains data depicting vegetation, grid squares, roads, rivers, contour lines and urban areas.

a. Waterways Experimentation Station (WES) Process

The Waterways Experimentation Station is part of the Corps of Engineers and has a mission of supporting the U. S. Army by means of geotechnical support. Terrain database development began with the creation of descriptions of basic terrain factors that effect the movement of mounted or dismounted units engaged in combat. WES's procedure for developing terrain databases involves preparing overlays that describe basic terrain factors of the specified test area [BULL 88]. These overlays are called primary factor maps. The primary factors associated with each basic terrain factor are: land use, slope, soils, obstacles and linear features. A listing of the components of the primary factors can be found in Appendix A. The primary factor maps are digitized and rasterized at the required resolution and combined with the terrain file to form the scenario terrain database.

b. PEGASUS Process

Only one process is used to produce the terrain file and screen file in PEGASUS. The PVDB contains the cultural feature indicators as well as the elevations. This is accomplished through the use of a 32-bit terrain element database that provides the information for surface objects such as rocks, trees, buildings, etc. The terrain database creation diagram, Figure 3, again shows the process for building and continuously updating the scenario terrain database.

D. TERRAIN MODIFICATION

All direct fire weapons are dependent on lines of sight (LOS) to be effective, and Javelin is a direct fire weapon. This simple, but crucial fact makes the representation of the actual terrain in the simulation model very important. The characteristics of the terrain are a key factor in LOS determination, and the LOS is a key factor in the detection of any

enemy element. There are two factors that effect LOS on the ground: [CELS 92]

- Elevation: The elevation level between forces must allow for LOS. If intervening crests mask the LOS between the sensor and the target, no direct fire occurs.
- Vegetation and urban areas: Trees and man-made objects can interfere with LOS. So, if vegetation and urban areas exist, they must be accurately represented in the model.

Janus(A) addresses both deterministic and probabilistic aspects of detecting a target. It addresses the deterministic aspect by calculating whether there is any type of terrain mask between the sensor and the target. The probabilistic aspects are addressed by determining if the target can be detected through vegetation or urban areas, by considering the density of the objects in the line of sight.

It has already been explained that the density and height of an object are assumed constant and uniform throughout a grid cell. However, the program modelers of Janus(A) also modeled an area or group of grid cells, that has a stand of trees as an area having homogeneous density and tree heights. A color picture of this Janus(A) representation for the Javelin test area is found in Appendix B. So, to ensure that the LOS for the Javelin correctly reflected the actual terrain, this study modified the Janus(A) scenario terrain using an eight meter terrain database derived from the PEGASUS one meter terrain database. The eight meter terrain database depicts the Fort Hunter Liggett area and was adapted to run on a personal computer. Within this database, the user is able to zoom in from a top down perspective to see individual trees. Also, when the user clicks the mouse on a particular piece of terrain, the military grid coordinates along with an elevation are displayed. This allows the user to more accurately place vegetation on the Janus(A) simulated terrain. The database is now the possession of TRAC-MTRY and the Janus(A) developers at TRAC-WSMR are attempting to modify the database program files so the

Janus(A) Terrain Research Program (TRP) can read the files into a Janus(A) two-dimensional display of the Fort Hunter Liggett area.

Next, an eight kilometer square area covering the Javelin test site area was modeled in Janus(A). Two copies of this scenario terrain were stored in separate files. Both files have a resolution of fifty meters. Then one of the files was modified using the eight meter PEGASUS database. In this scenario file, a vegetation code was placed on, or removed from, each fifty meter grid cell and the density of each grid cell was also changed, if needed. Subjective judgement was involved in the areas of density and tree height and whether or not a grid cell needed trees in it. The tree heights can be changed within the terrain editor. However, there is a basic problem with the way the tree heights are handled. The tree heights are tied to the density codes. This means that for a density code of five a corresponding tree height can be set to eleven meters or any other value you pick. The problem is, the tree height then applies for all densities of five in the scenario terrain. The model does not take in consideration that different types of trees can be found in the same scenario area (e.g., deciduous stand of trees and an orange grove) or a younger stand of trees may populate a certain sector of the scenario terrain. For the test site area, the majority of the trees observed on two different terrain walks were approximately nine to thirteen meters high. This was verified by forestry sources on the post. There was a problem of determining whether trees were needed in a certain grid cell and the correct density of trees for a particular grid cell. This was solved be looking at the number of trees per fifty meter square area and how close the trees were to each other.

Although, subjective judgement was used to modify Janus(A) terrain, the belief is that the modified terrain will better represent the actual test site terrain. A color picture of the default and modified terrain can be found in Appendix B.

E. JANUS(A) SUFFICIENCY TO MODEL REAL WORLD TERRAIN

As stated, Janus(A) is widely used throughout the Army to model ;jade and lower combat operations. Even though Janus(A) is an approved simulation model for the above use, is Janus(A) sufficient to model an operational test? This thesis assumes that the Janus(A) model terrain can sufficiently represent real world terrain for modeling purposes.

Currently, there are two methods for modeling terrain. Both of these methods have been proven to represent real world terrain adequately. The most widely used method is the plateau method. Janus(A) uses the plateau method. In this method grid cells encapsulate the terrain characteristics, and one elevation value is assigned to each cell. At the respective resolution (e.g., 50x50 meter) a system of pilings with flat tops (plateaus) are created which represent the real world terrain. This causes a stepwise jump or drop transition to each grid cell. Real world terrain flows in a more continuous fashion except at cliffs and sinkholes. However, as the resolution is increased to twelve meters or six meters the plateau method smooths out considerably, depending on the area being modeled. This method also lends itself to translation into UTM grid coordinates which are the bases for the military grid coordinate system.

The other method of modeling terrain is called the polygonal method. In this method, straight lines are connected to designated elevation points. This creates a series of slopes that can be translated into a digital contour map. The contour map is then overlayed with a digitized screen file with the result that represents real world terrain. However, this method does not lend itself to easy translation into the military grid coordinate system.

IV. ANALYSIS AND DISCUSSION OF JANUS(A) MODEL TERRAIN

A. GENERAL

The analysis was conducted in the last two phases. In phase two, the vegetation code distributions in the default and modified terrain databases were compared to see if the differences were more substantial than would be expected because of natural variation. In the third phase, three actual IOTE scenarios were simulated using each database to see if the test results would be effected. This phase was done because the vegetation codes for the terrain files are different.

For the analysis, a sample one kilometer square was extracted from each terrain file. These terrain squares represented the same patch of land in each file. Using the Janus(A) terrain utilities, the vegetation codes for each one kilometer sample were recorded for analysis. In Janus(A) the vegetation codes can only take the the value of discrete integers from zero to seven. A total of 800 vegetation data points were collected, 400 for each terrain sample. These observations represent the entire vegetation code population for each selected one kilometer; the same one kilometer square was chosen from each database. The question to be answered was not whether the two populations were different, the known changes ensured that they were different. But, did the changes that were required to make the modified one kilometer square terrain more accurately reflect the actual terrain result in differences more substantial than would be expected between two one kilometer squares chosen at random. Parametric, nonparametric and graphical statistical analysis techniques were used to compare and contrast the vegetation code distributions. The analytical software packages used in this thesis were the statistical package SPSS and A Graphical Statistical System (AGSS). AGSS is available for use at the Naval Postgraduate School (NPS) under a test site agreement with IBM Research. We are indebted to Dr. Peter Welch for making this possible.

First, graghical tests for normality were conducted on the vegetation code data from each sample to determine if parametric techniques were appropriate. As can be seen in the following section, neither vegetation code distribution is well approximated by the normal distribution. Therefore, nonparametric and graphical tools were used in the analysis. Note that it is acceptable to use nonparametric techniques for data that does follow the normal distribution. Nonparametric procedures perform almost as well as the *t* and *F* tests for normal data , and will often perform much better under non-normal conditions [DEVO 87]. Graphical tools were used to provide visual insights into the data distributions.

Next, three scenarios from the Initial Operational Test and Evaluation (IOTE) for the Javelin antitank weapon were run on each the default and modified terrain files. The scenarios: a night deliberate defense, a day hasty defense and a day deliberate defense were set up to be run on the Janus(A) simulation model by CPT Mick McGuire for his thesis <u>The Javelin Versus the Dragon II, A Comparative Analysis.</u> These scenarios were imported from CPT McGuire's database in a cooperative effort to improve the Javelin IOTE. The three scenarios were each run eight times on each terrain file for a total of 48 runs. The measure of effectiveness (MOE) was the detection range of an enemy target by either force. This MOE was used because detection is greatly effected by the vegetation represented in the terrain database.

B. ANALYSIS OF TERRAIN VEGETATION

The first test on the terrain samples was a test to determine if the terrain sample vegetation codes were from the normal distribution. Normal probability plots and detrended normal plots were was used to determine if nonparametric or parametric statistical procedures should be used to analyze the data. The normal probability plot pairs each observed value with its expected value from the normal distribution. If the sample is from the normal distribution the points should fall more or less on a

straight line [MEND 90]. Figure 6 shows that the points do not cluster around a straight line and in Figure 7 shows that the deviations from the straight line, the detrended residuals, are not randomly distributed around zero.

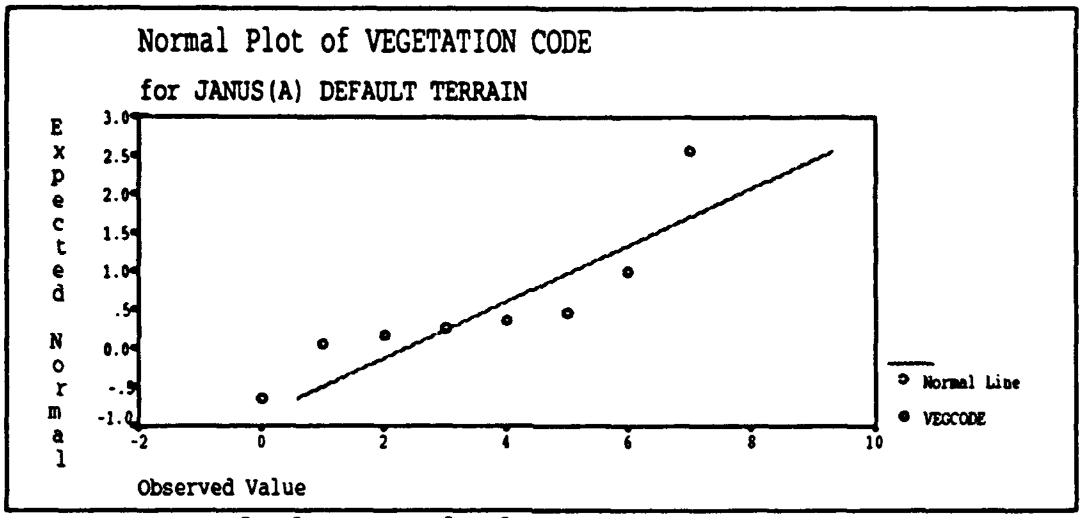

Figure 6 Default Normal Plot

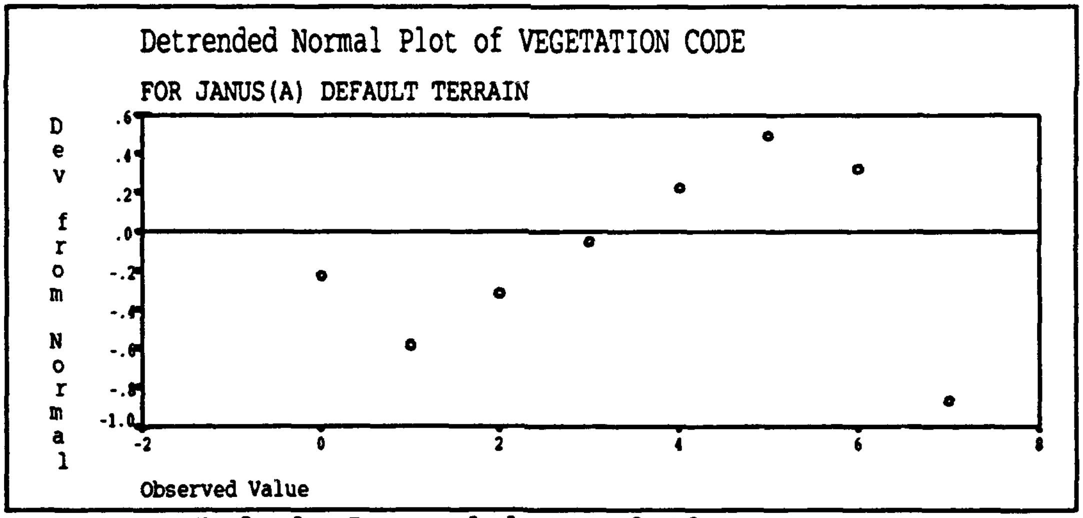

Figure 7 Default Detrended Normal Plot

Likewise, the data points for the Janus(A) modified terrain do not fall along the straight line in Figure 8, and the detrended normal plot,

Figure 9, shows a lack of randomness in the dispersion of the residuals.

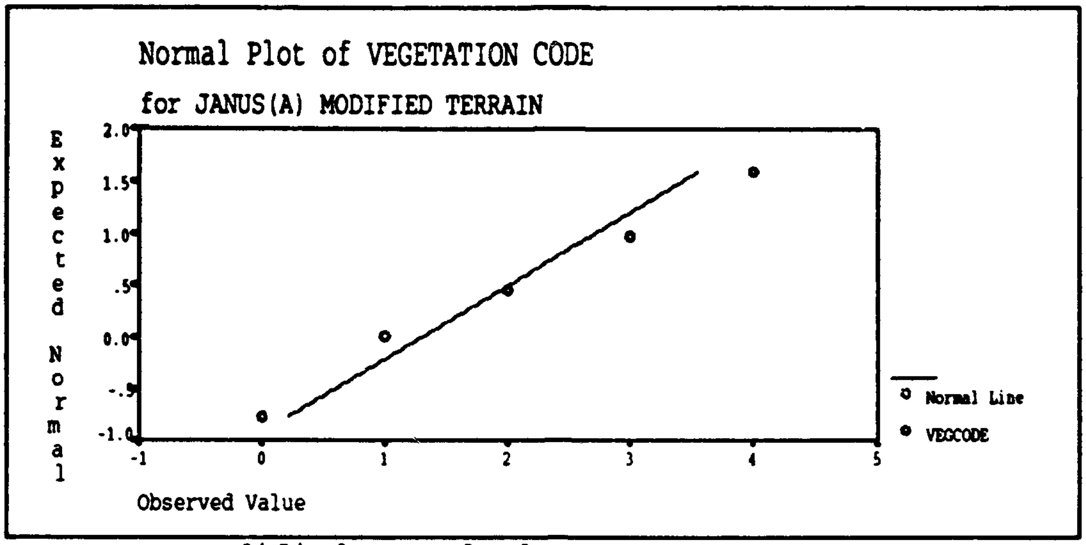

Figure 8 Modified Normal Plot

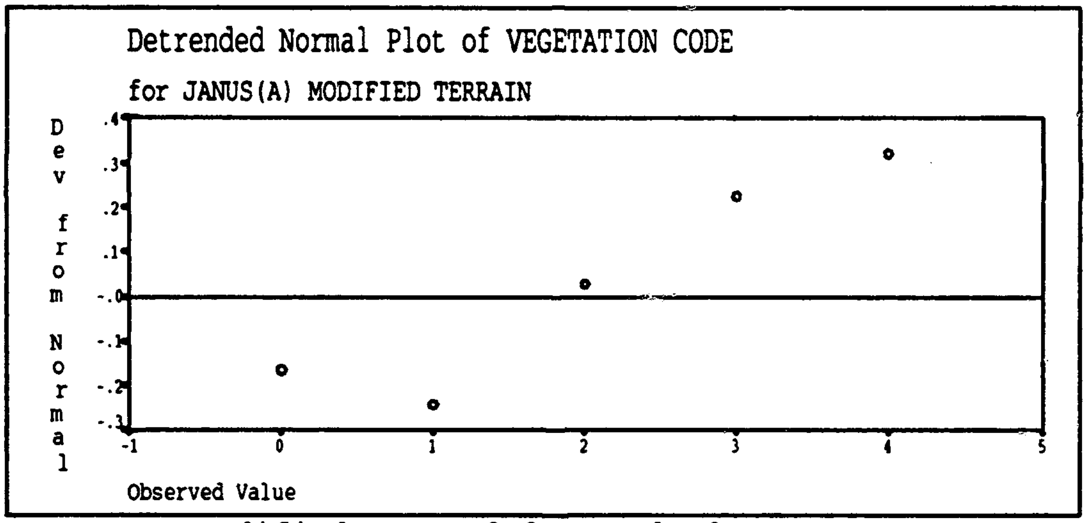

Figure 9 Modified Detrended Normal Plot

These four plots indicate that the vegetation code data in the default and modified Janus(A) terrain do not follow the normal distribution. Therefore, nonparametric and graphical techniques will be used as the analysis tools. By looking at the graphs it cannot easily be determined that 400 data points per terrain sample were used in this analysis process.

This is because the vegetation codes can only take the value of discrete integers from zero to seven. Therefore, the data for both terrain samples was plotted using a bar graph. Figure 10 graphically confirms that the vegetation codes do not follow the normal distribution, and further indicates that their distributions are not similar.

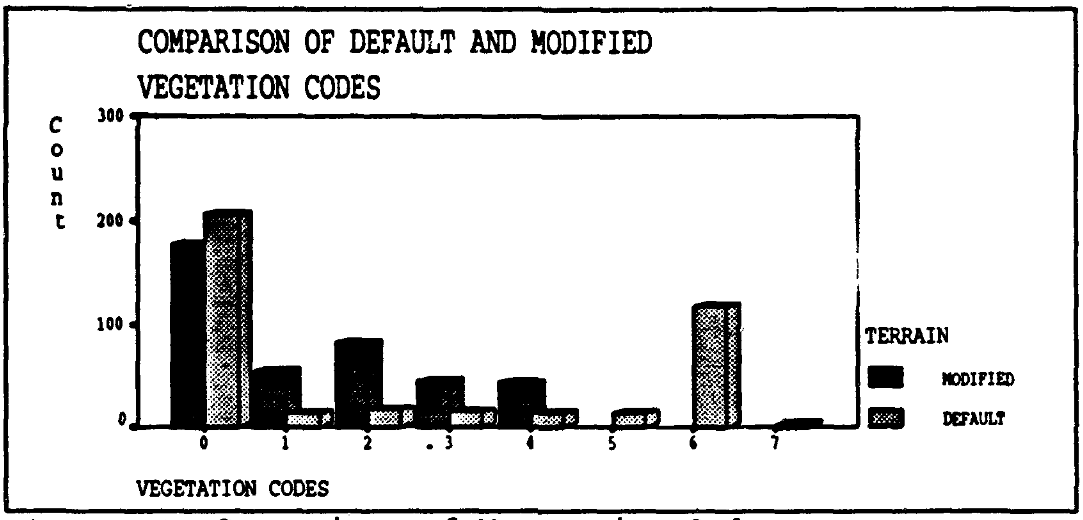

Figure 10 Comparison of Vegetation Codes

In sum, the preceding five graphs indicated that the vegetation codes for the default and modified terrain did not follow the normal distribution. Therefore, the assumption of normality could not be made and nonparametric and graphical techniques were used to analyze whether the vegetation codes in the two terrains files were similar. The Mann-Whitney test was used to test the null hypothesis that the population relative frequency distributions for the two terrain samples are identical [MEND 90]. The least restrictive alternative is that one distribution is stochastically larger than the other [GIBB 92]. The Mann-Whitney test requires the assumption of two independent random samples from continuous distributions. The vegetation code samples clearly do not satisfy that assumption. However, the test results do answer the question; "Would two independent random samples from the same vegetation code distribution be

expected to exhibit differences similar to those between the default and modified terrain samples?" The answer is clearly no. The following table shows the results of the Mann-Whitney test.

Table II VEGETATION CODE MANN-WHITNEY TEST

Mann-Whitney U Test

VEGCODE
by TERRAIN

Mean Rank	Cases	
376.41	400	TERRAIN = Modified
424.59	400	TERRAIN = Default

	800	Total

U	W	Corrected for ties Z	2-Tailed P
70365.0	150565.0	-3.1360	.0017

After the vegetation codes are merged and ranked, the U statistic represents the number of times *a modified terrain vegetation code* value preceeds a value for the default terrain vegetation code. The very large value of U indicates there is a separation of the ordered modified and default vegetation code observations and indicates a stochastic difference between the distributions. Since the significance level is small (less than .025, for a two tailed test) the null hypothesis that the two vegetation code distributions are the same is rejected. It is concluded that the vegetation codes in the Janus(A) modified terrain are stochastically different from the vegetation codes in the Janus(A) default terrain.

The distrbutions of the two vegetation code samples are not known, but the following graph, Figure 11, provides some detailed comparisons of the distributions of the two data sets. The graph is an empirical quantile-quantile plot and is constructed by plotting the quantiles of one empirical

distribution against the corresponding quantiles of the other [CHAM 83]. If the distributions were identical, all the points would lie on the line $y = x$. The points do not lie on the $y = x$ line, thus the distributions are not identical. Because most of the points lie below the $y = x$ line, it is clear that the Janus(A) default terrain has the higher vegetation density codes. Also, because the data points are discrete integers they form a stepwise linear curve.

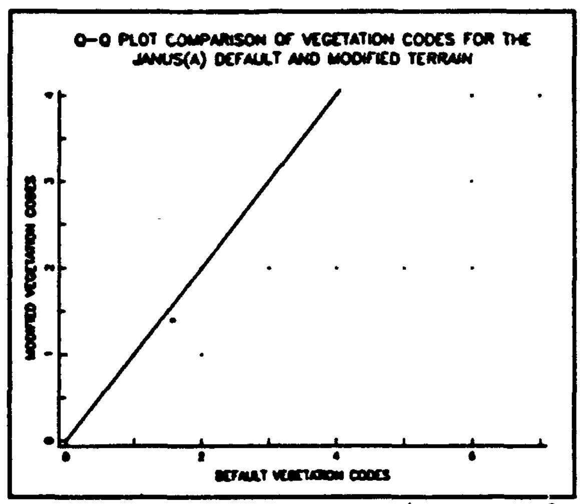

Figure 11 Vegetation Code Quantile-Quantile Plot

C. ANALYSIS OF THE SCENARIO RUNS

It has been determined that the vegetation codes in the two terrain files are stochastically different. Intuition indicates that if the same scenario was run on each terrain file, the detection ranges should also come from different distributions. This section will explore this hypothesis. In this analysis, vegetation code distribution will be treated as a factor at two levels: default and modified.

The scenarios consisted of a U.S. light infantry company team - BLUE force and a North Korean mechanized platoon - RED force. The light infantry team is equipped with M16 rifles, a 60mm mortar section, squad

automatic weapons (SAW), M60 machine guns, light antitank weapons (LAW) and Javelin medium antitank weapons. The company team is also augmented with a heavy mortar section. The North Korean platoon is organized with three T72 tanks, three BMPs and a heavy mortar section. The BLUE and RED forces have 119 and 41 personnel, respectively. The tactical employment of the forces follows the known warfighting doctrine of each country.

To prevent a learning effect when running the scenarios, each run was conducted using the Automatic Janus(A) mode. In this mode, the computer runs the scenario on saved puck movements (player actions) which were made by the initial man in the loop interactive battle. The probabilistic outcomes (detection, kill, etc.) are not necessarily the same, so the data can be viewed as independent, random samples.

1. The Night Deliberate Defense

The first scenario was the night deliberate defense. In the terrain area where this battle took place, there were many modifications to the vegetation. These differences were captured in the following descriptive summary.

Table III NIGHT DELIBERATE DEFENSE DETECTION RANGE SUMMARY

	DEFAULT	MODIFIED
MEAN	2.52	2.29
S.E. MEAN	.03	.04
STD DEV	.92	1.12
MINIMUM	.01	.01
MAXIMUM	4.32	4.46
TOT OBS	715	952

Next the Mann - Whitney test was used to test the null hypothesis that the population relative frequency distributions for the two detection range samples are identical. The significance level was .0004; therefore, the null hypothesis is rejected. The population relative frequency distributions for the detection ranges in the night deliberate defense for the two terrain files were significantly different.

Table IV NIGHT DELIBERATE DEFENSE MANN-WHITNEY TEST

```
Mann-Whitney U Test

    DETECTRG
 by TERRAIN

      Mean Rank     Cases

        882.43        715   TERRAIN = Default
        797.62        952   TERRAIN = Modified
                     ----
                     1667   Total

                                      Corrected for ties
          U              W                 Z       2-Tailed P
      305710.5       630939.5          -3.5601        .0004
```

A graphical depiction showing the differences between the two detection range samples is shown in Figures 12 and 13 on the following page.

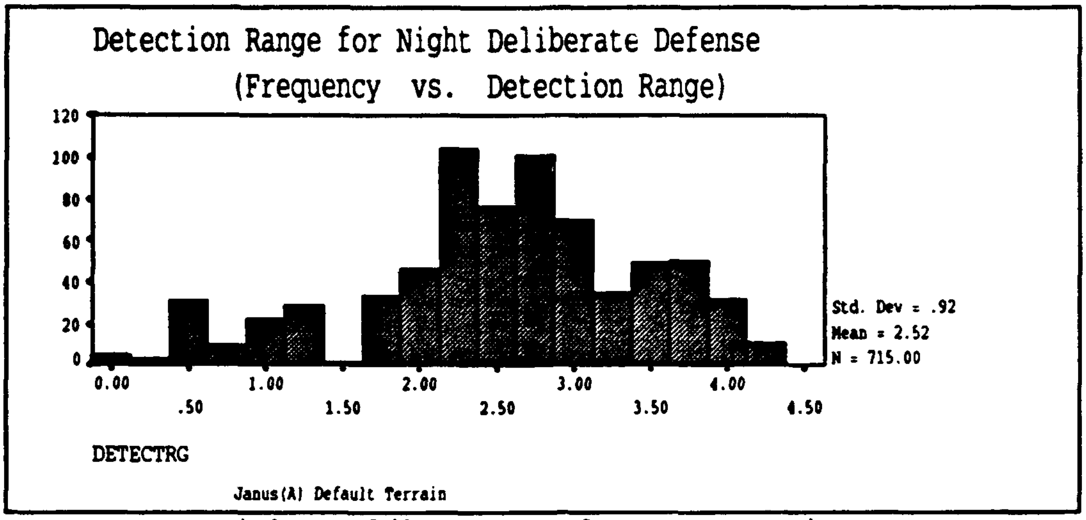

Figure 12 Night Deliberate Defense Detection Ranges

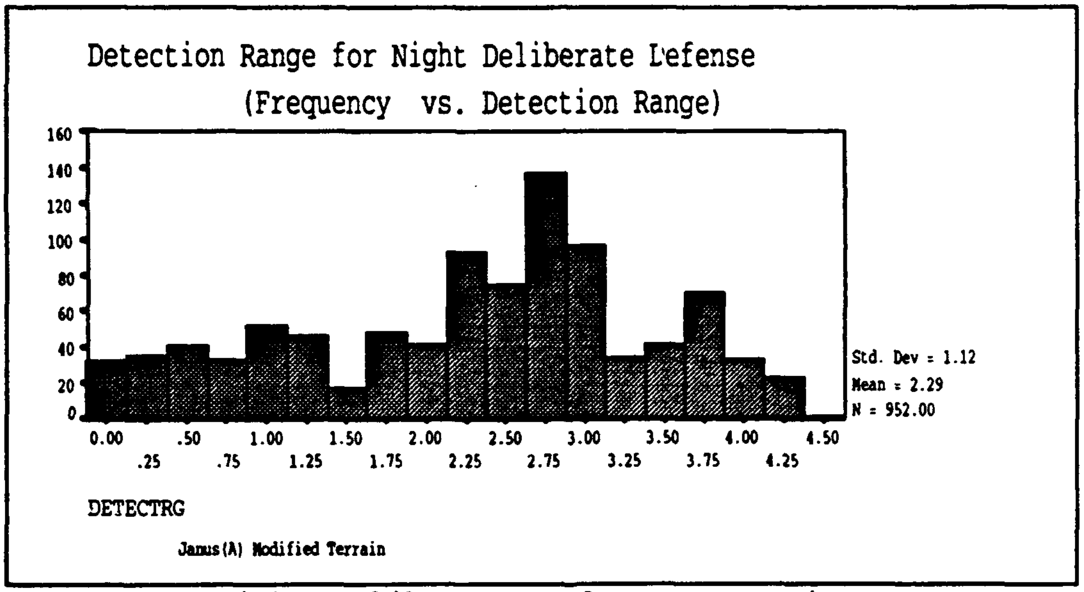

Figure 13 Night Deliberate Defense Detection Ranges

The quantile-quantile plot for the night deliberate defense, Figure 14, shows that the distributions of the sample detection ranges for the default terrain and the modified terrain are not the same. Below 2.75 kilometers the default terrain detection ranges were greater. Interestingly, the detection ranges for the modified terrain are similar

to the detection ranges for the default terrain for distances beyond 2.75 kilometers. This could be explained by a similarity in the terrain vegetation codes for the particular areas modeled and the use of infared sensors to detect targets at these ranges.

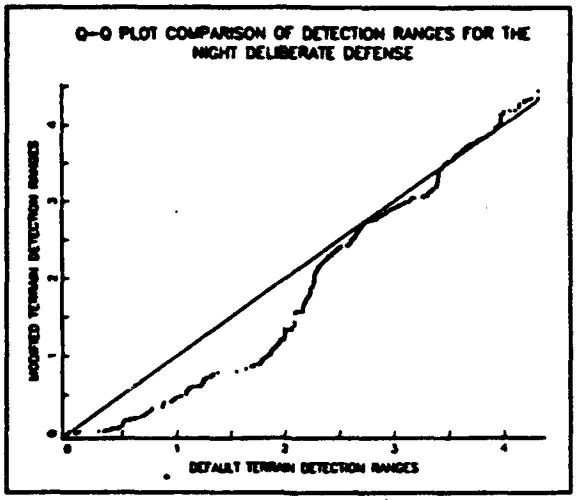

Figure 14 Detection Range Quantile-Quantile Plot

2. The Day Hasty Defense

The second scenario was the day hasty defense. The terrain in this area also required numerous modifications to the vegetation. These differences were captured in the following descriptive summary.

Table V DAY HASTY DEFENSE DETECTION RANGE SUMMARY

	DEFAULT	MODIFIED
MEAN	2.31	1.37
S.E. MEAN	.02	.03
STD DEV	.51	1.06
MINIMUM	.03	.01
MAXIMUM	2.89	2.91
TOT OBS	945	1306

Again the Mann - Whitney test was used to test the null hypothesis that the sample population relative frequency distributions for

the two detection range samples are identical. The significance level was .0000. The population relative frequency distributions for the detection ranges in the day hasty defense for the two terrain files were significantly different.

Table VI DAY HASTY DEFENSE MANN-WHITNEY TEST

```
Mann-Whitney U Test

    DETECTRG
  by TERRAIN

     Mean Rank     Cases

       1396.58       945  TERRAIN = Default
        930.21      1306  TERRAIN = Modified
                    ----
                    2251  Total

                                     Corrected for ties
           U            W               Z        2-Tailed P
     361385.0     1319770.0      -16.8017           .0000
```

The histograms on the following page graphically show the differences between the two detection range samples, Figures 15 and 16.

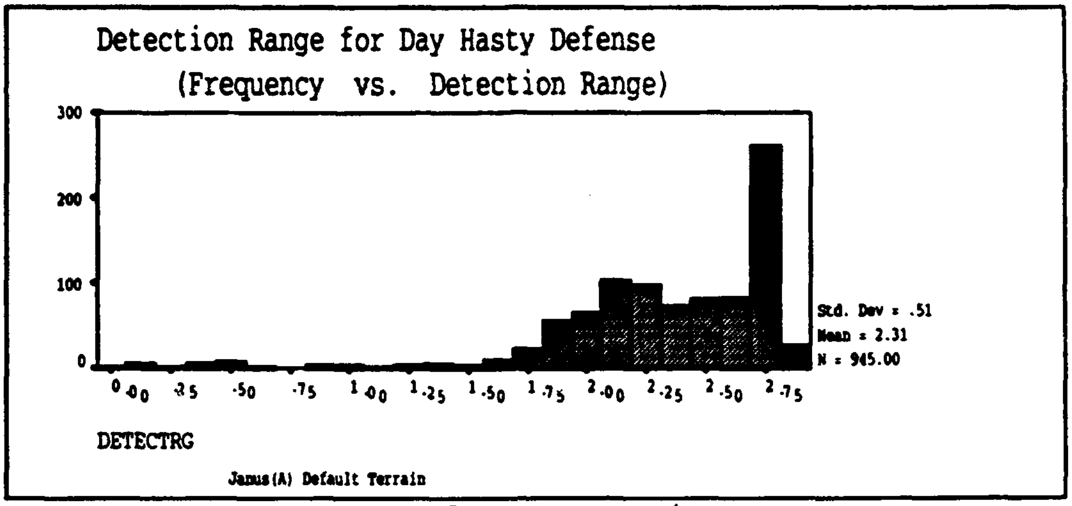

Figure 15 Day Hasty Defense Detection Ranges

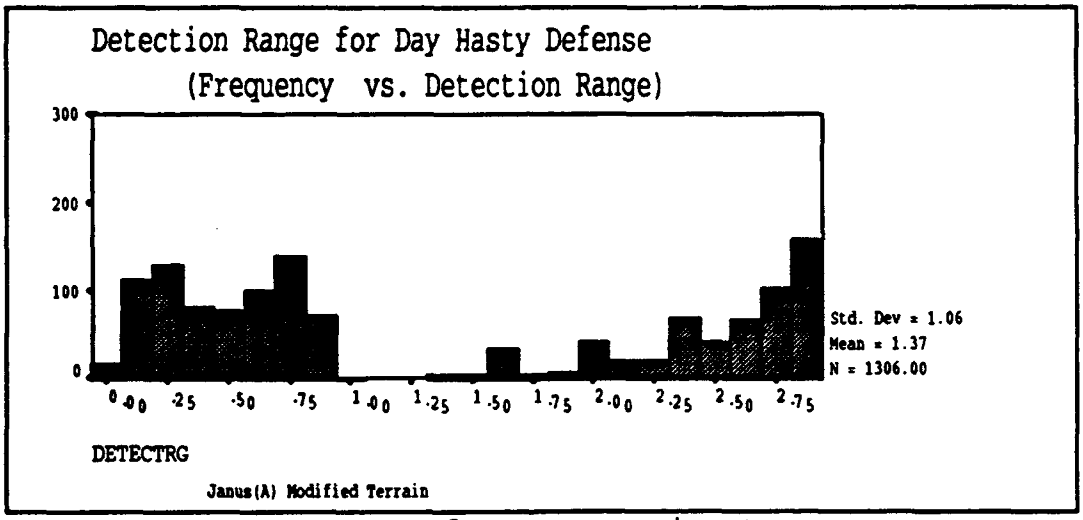

Figure 16 Day Hasty Defense Detection Ranges

The quantile-quantile plot, Figure 17, for the day hasty defense shows that the default terrain sample detection ranges are much greater than those for the modified terrain. The detection range distributions for the two terrains are clearly not identical.

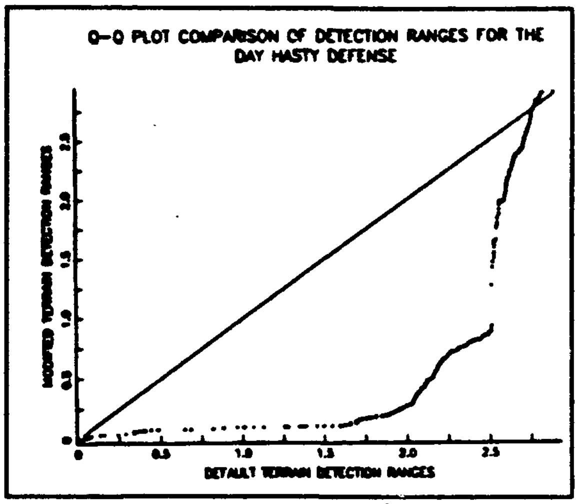

Figure 17 Detection Range Quantile-Quantile Plot

3. The Day Deliberate Defense

In the last scenario, the majority of the engagement area was in an open area. Intuitively the modifications to the terrain should have little effect on the detection ranges for the two samples. The following descriptive summary indicates the similarities between the two detection range samples.

Table VII DAY DELIBERATE DEFENSE DETECTION RANGE SUMMARY

	DEFAULT	MODIFIED
MEAN	1.69	1.71
S.E. MEAN	.04	.03
STD DEV	.95	.86
MINIMUM	.08	.02
MAXIMUM	3.81	4.46
TOT OBS	658	983

The Mann - Whitney test showed a significance level of .2267. The null hypothesis that the population relative frequency distributions for the two detection range samples are identical is not rejected.

Table VIII DAY DELIBERATE DEFENSE MANN-WHITNEY TEST

```
Mann-Whitney U Test

    DETECTRG
 by TERRAIN


      Mean Rank     Cases

         838.28       658  TERRAIN = Default
         809.43       983  TERRAIN = Modified
                     ----
                     1641  Total

                                        Corrected for ties
           U              W                Z        2-Tailed P
      312034.0       551591.0          -1.2089         .2267
```

The following two histograms also show the distinct similarities between the detection range populations for the two samples, Figures 18 and 19.

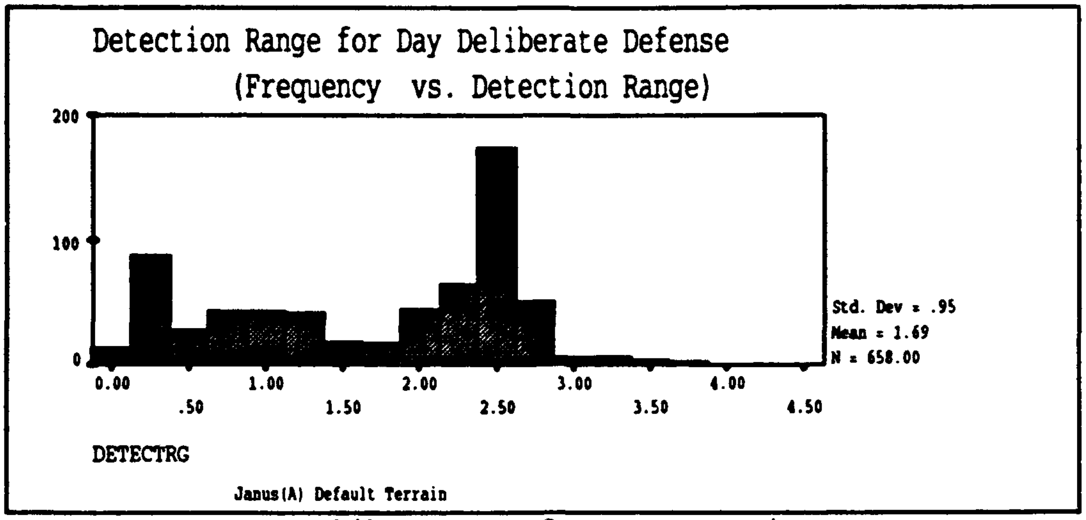

Figure 18 Day Deliberate Defense Detection Ranges

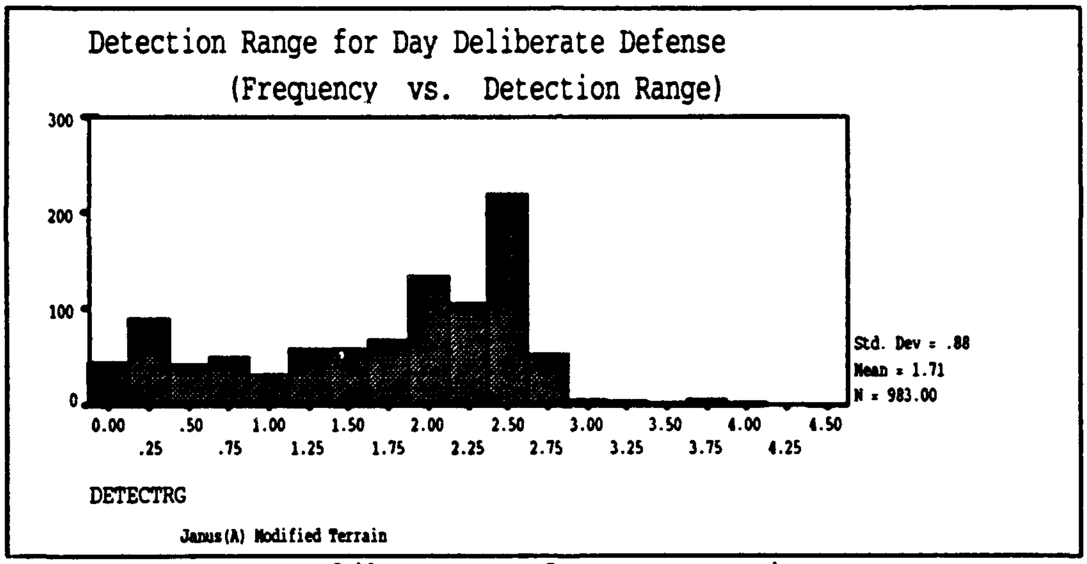

Figure 19 Day Deliberate Defense Detection Ranges

In the day deliberate defense scenario the distribution of the sample detection ranges for the default and modified terrain are not identical. However, they are similar (Figure 20), and an assumption that the distributions are equal is reasonable.

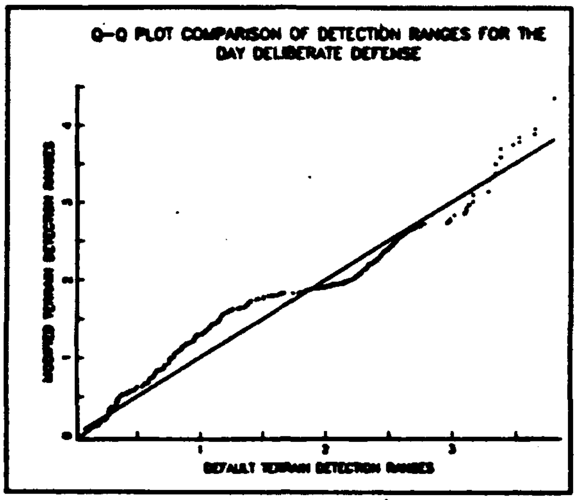

Figure 20 Detection Range Quantile-Quantile Plot

4. Aggregated Detection Ranges

The final analysis was conducted on the aggregated detection ranges for the scenarios on the default and modified terrain files. After conducting analysis on each scenario and showing that they are different, it seems to be wrong to aggregate the data. An analysis of the aggregated data was conducted because the scenarios of an IOTE are part of a larger unit operation. These operations are usually 72 or 96 hours and are composed of any number of scenarios. Thus, the aggregated data provides the proponency agency insights into the distribution of the entire operational scenario.

The results of the analysis showed the significance level to be .0000. The population relative frequency distrbutions of the two detection ranges are not identical.

Table IX AGGREGATED DETECTION RANGE MANN-WHITNEY TEST

```
Mann-Whitney U Test

    DETECTRG
 by FILTER_$  Filter Status


      Mean Rank     Cases

        3151.13      2318  FILTER_$ = Default Terrain
        2514.56      3241  FILTER_$ = Modified Terrain
                     ----
                     5559  Total

                                      Corrected for ties

             U              W              Z      2-Tailed P
      2896033.0      7304326.0       -14.5814          .0000
```

Figures 21 and 22 on the following page also show the differences in the two detection samples.

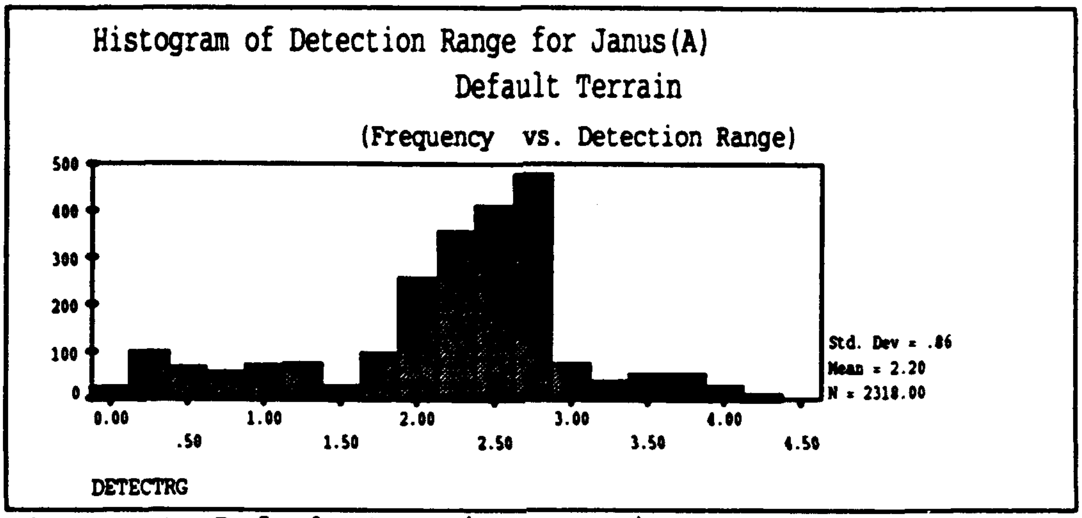

Figure 21 Default Terrain Detection Ranges

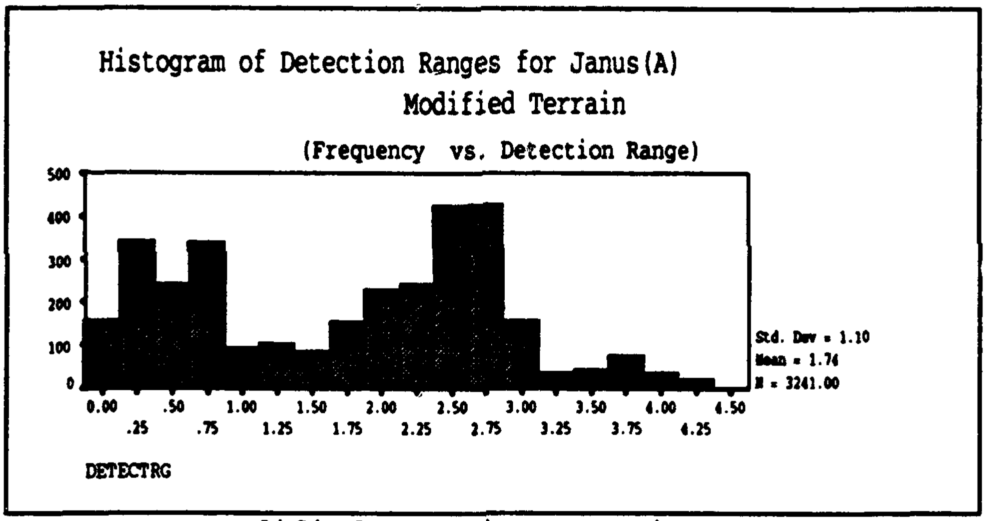

Figure 22 Modified Terrain Detection Ranges

The quantile-quantile plot of the aggregated detection ranges for the two terrain files, Figure 23, shows that their distributions are not similar. At ranges greater than than 2.8 kilometers the sample detection range distributions are not identical but they are similar. Below 2.8 kilometers the detection ranges are greater for the default terrain.

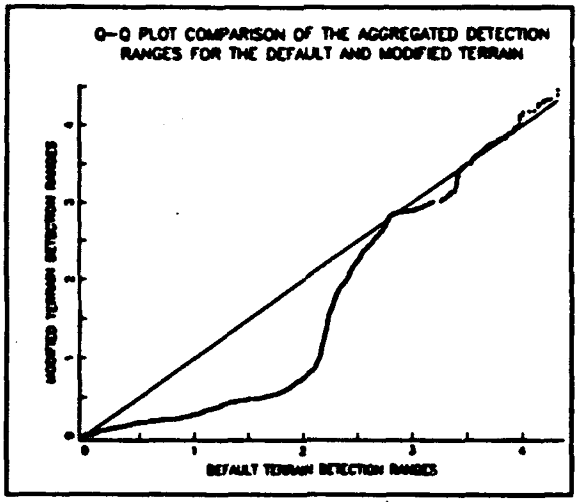

Figure 23 Detection Range Quantile-Quantile Plot

D. ANALYSIS SUMMARY OF THE SCENARIOS

The analysis indicated that the vegetation code distributions for the default terrain and the modified terrain are different. Also the detection range distributions for the two terrain files in each scenario were not identical. In all but one case, the analysis indicated that the terrain had a significant effect on the detection ranges. The day deliberate defense was conducted in an area where only minimal terrain modifications were needed. This area was virtually devoid of vegetation. Therefore, the lack of any statistical difference between the modified terrain and default terrain detection ranges was expected. The detection range distributions for the day deliberate defense could be assumed to be the same because of their similarities.

V. CONCLUSIONS/RECOMMENDATIONS

A. SUMMARY OF FINDINGS

The purpose of this thesis was to compare and analyze the effects of the Janus(A) default terrain and the Janus(A) modified terrain on the simulated Javelin antitank weapon operational test. The results suggested that modifying the vegetation codes to better represent the actual test site terrain will result in a significant difference in the detection ranges. This means that the lines of sight (LOS) for direct fire combat systems when employed on the modified terrain will be significantly different than those employed on the default terrain.

This analysis does not invalidate the Janus(A) model using the default terrain. However, this analyst believes better results could be obtained by improving the current terrain database.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

The findings of this thesis suggest the following recommendations for further research on the Janus(A) terrain database:

- There seems to be a need for a higher resolution terrain database to capture these terrain features. The fifty meter resolution does not provide accurate enough detail to represent vegetation, small rolling hills or other obstacles that effect the LOS of the model.

- Research needs to be conducted to more accurately represent the size and shape of a particular type of cultural feature in a geographic region (i.e., coniferous trees, deciduous trees, orchards, rock croppings, etc). This modeling effort should also look to represent these features from a ground level view as well as from an aerial view. The Perspective View Generator and Analysis Systems for Unmanned Sensors (PEGASUS) replicator has made inroads in this area.

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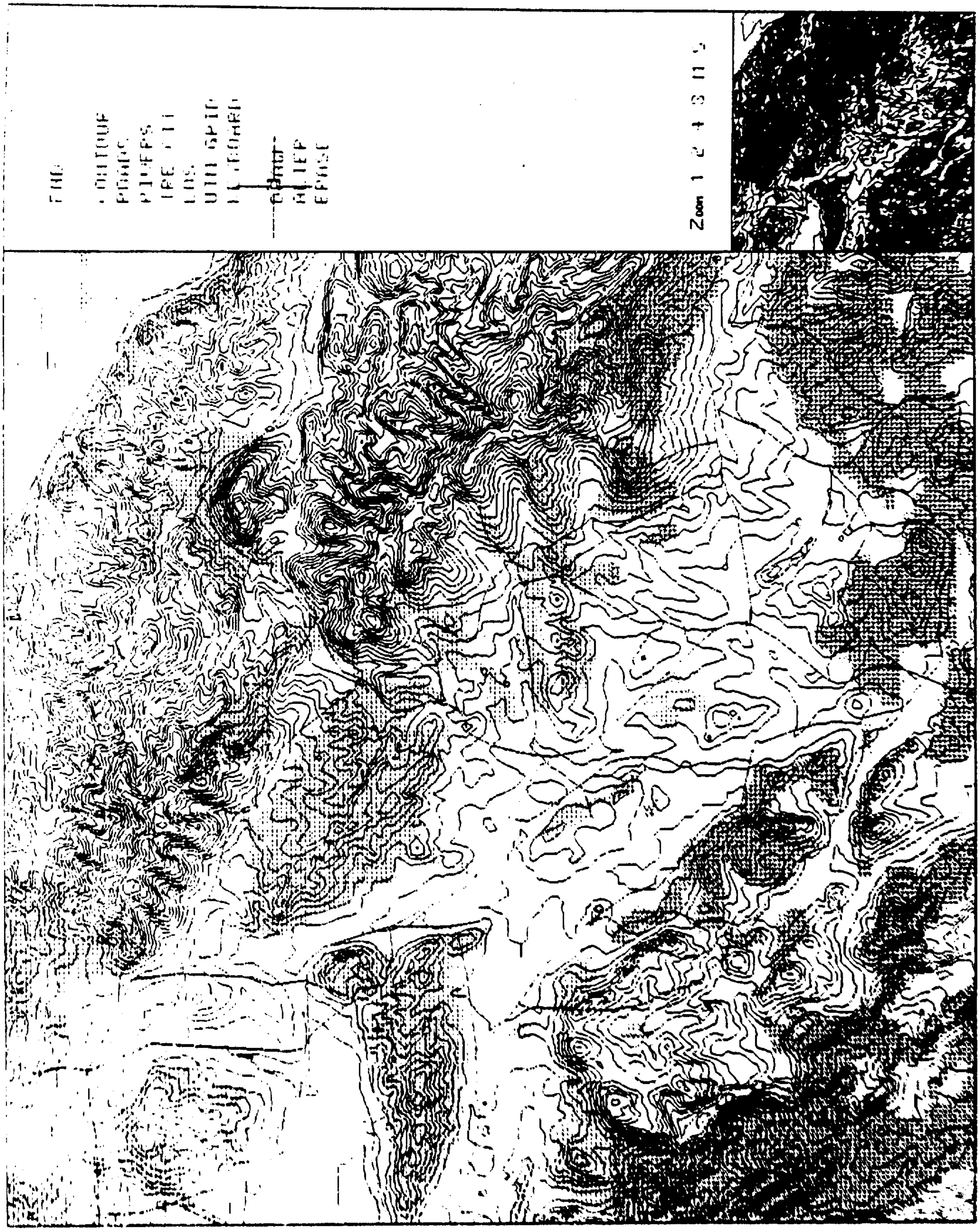
APPENDIX A: PRIMARY FACTORS

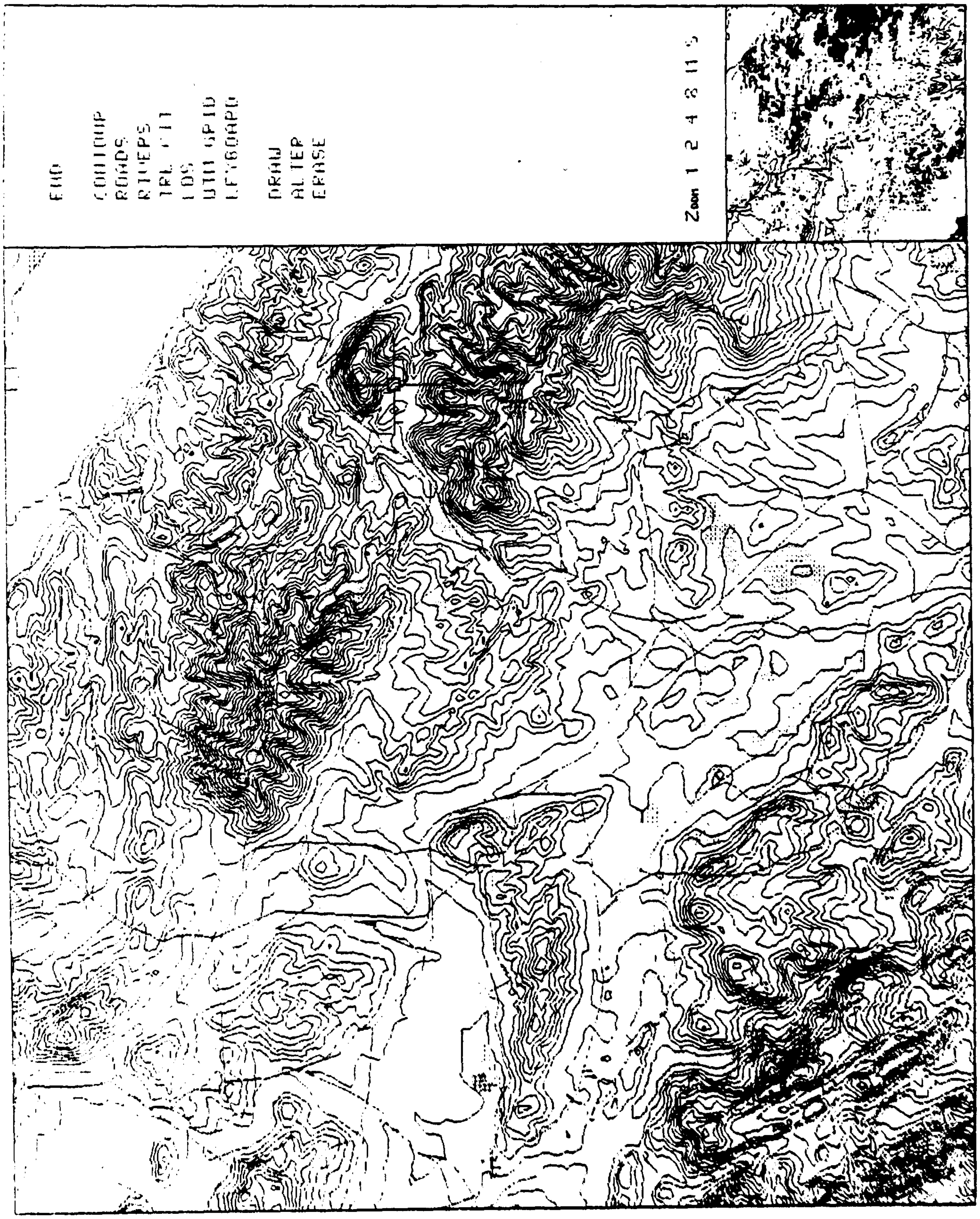
These are the primary factors associated with each basic terrain factor used in the Waterways Experimentation Station (WES) process.

- Land use
  - General land use
  - Forest stands
  - Agricultural crops
  - Understory density
  - Urban structures
  - Embankments
- Slope
  - Slope, percent
  - Azimuth, degree
  - Elevation, meter
- Soils
  - Soil type
  - Depth of soil
- Obstacles
  - General vertical obstacles
  - Embankments
  - Roadside ditches
- Linear features
  - Roads
  - Rivers and streams
  - Embankments
  - Roadside ditches

APPENDIX B: JANUS(A) DEFAULT AND MODIFIED SCENARIO TERRAIN

The first picture shows the Janus(A) default terrain for the Javelin test area. As can be seen, the vegetation areas have a homogeneous density over a particular area. The second picture shows the Janus(A) modified terrain. There is a marked difference in the densities of vegetation areas compared to the default terrain. Both sets of terrain have a resolution of 50 meters and a contour interval of 33 feet.

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